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Polybrominated diphenyl ethers (PBDEs) in car and house dust from Thailand: Implication for human exposure

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Abstract

This study reports concentrations of tri- to hexa-bromodiphenylethers (BDEs 17, 28, 47, 49, 66, 85, 99, 100, 153 and 154; Σ_{10}PBDEs (polybrominated diphenyl ethers)) in car (n=30) and house dust samples (n=53) collected from different provinces in Thailand. Levels of Σ_{10}PBDEs in vehicle and domestic dust were 0.68-38 and 0.59-260 ng g^{-1}, respectively. BDEs 99 and 47 were the most abundant congeners in all automobile and residential dust samples. A t-test analysis indicated that Σ_{10}PBDE concentrations in dust samples from dwellings exceeded significantly those from cars (p = 0.001). Furthermore, contents in dust of all PBDEs studied, except for BDE-28, were significantly higher in homes than in vehicles (p = 0.000-0.004). Principal Component Analysis (PCA) demonstrated no differences in PBDE congener patterns between Thai house and automobile dust, but revealed some subtle differences in the congener pattern between household dust samples in Thailand and those reported previously for the United Kingdom. Estimated environmental exposure of Thai adults and children for BDE-99 via dust ingestion were well within a chronic oral reference dose (RfD) for BDE-99 (100 ng/kg bw/day) proposed by the United States Environmental Protection Agency (US EPA).

Keywords: Polybrominated diphenyl ethers (PBDEs), indoor dust, home, car, exposure

Introduction

~~At present, some of the critical environmental problems are caused by P~~Persistent organic pollutants (POPs) are acknowledged to be of international concern. [1,2] Recently, PBDEs (polybrominated diphenyl ethers) constituting the Penta- and Octa-BDE commercial formulations have been listed as POPs under the terms of the United Nations Environment Programme (UNEP) Stockholm Convention. [3,4] As POPs, PBDEs are global contaminants of concern [5-9] with potential for long-range atmospheric transport (LRAT), deposition and revolatilization along with accumulation and magnification in humans, wildlife, and ecosystems. [10-17] PBDEs are also toxicants of particular significance to human health because they affect neurobehavioral development, endocrine systems and thyroid hormones as well as possibly causing cancer. [18-21]

PBDEs are one of the most widely used brominated flame retardants (BFRs). [22] They are added to polymers used in furniture, electronic circuitry, plastics, textiles, building and construction materials, automotive and aeronautic parts as well as other products to prevent the spread of fires. [23] PBDEs have been used extensively as three formulations: decabromodiphenylether [Deca-BDE]; octabromodiphenylether [Octa-BDE]; and pentabromodiphenylether [Penta-BDE]. [24]

Thailand does not have strong regulatory control over PBDE applications. [25] BDEs 47, 99, 153, 154, 175 and 183 will ~~recently~~ soon be added to the Thailand Hazardous Substances List which is annexed to the Notification of Ministry of Industry on List of Hazardous Substances (No.4) B.E. 2560, dated 15th December B.E. 2560 (2017). [26] Thus, PBDEs may be found in a wide range of consumer products, including electronics, furniture and car seats. They are added to polymers during polymer manufacture, but are not chemically bonded to the polymers, and so can readily migrate from these materials to the surface [27,28] and then into the surrounding environments through a variety of routes such as volatilization or dust formation during the use of treated products in homes and automobiles. [29,30] Unsurprisingly, owing to the fact that PBDEs have been greatly used in indoor applications especially indoor and household products, elevated levels are detected in indoor environments. [31-33] Indoor dust and air have been documented as primary sources of human exposure to PBDEs. [34-36] Residential dust contributes to 82% and 77% of the U.S. adult and toddler PBDE exposure [35,37], and contributes more than 80% of exposure for Canadian children. [32,36] Toddlers and children likely are at the greatest risk from ingestion and inhalation exposure because they sit, crawl or roll on floors and place objects in their mouths (hand-to-mouth behavior). [16,37]

Car dust was~~ere~~ also sampled in this study because several PBDE-treated items, including seat polyurethane foam, electronics and textiles, are applied in the automotive parts and may contain PBDEs. [38] Harrad et al. [39] stated that the median concentrations of PBDEs in automobile dust exceeded those in domestic dust. Moreover, high temperatures in Thailand could lead to the greater emission from PBDE-containing products in vehicles than in other indoor environments. [40]

In Thailand, information on PBDE contamination is still very limited. The present study is the first to characterize PBDE contamination in Thai vehicles. The principal objectives were: (i) to determine concentrations of tri- to hexa-bromodiphenylethers (BDEs 17, 28, 47, 49, 66, 85, 99, 100, 153 and 154; Σ_{10}PBDEs) in car and household dust sampled from different provinces in Thailand; (ii) to compare PBDE levels with those observed for domestic indoor dust and car dust in studies from other countries; and (iii) to evaluate exposure of the Thai population to the target PBDEs via dust ingestion.

Materials and methods

Target chemicals

In this study, tri- to hexa-BDEs (Σ_{10}PBDEs) were quantified in residential dust and automobile dust samples. Σ_{10}PBDEs were defined as the sum of BDEs 17, 28, 47, 49, 66, 85, 99, 100, 153 and 154.

Sampling locations and sample collection

53 house and 30 car dust samples were collected from 28 homes and 30 cars in different provinces of Thailand between December 2007-January 2008 using a Hitachi CV-BL16 1600 W vacuum cleaner via previously published methodology. [25,39, 41] In brief, dust was collected in a 25 µm pore size nylon sock positioned in the furniture attachment of the vacuum cleaner, with the attachment cleaned between sample collections to prevent cross contamination. In each home, four m^2 of bare floor or one m^2 of carpeted floor was thoroughly and evenly vacuumed for exactly 4 or 2 minutes, respectively. In each car, the front and rear seats, parcel shelf and dashboard were thoroughly and evenly vacuumed for exactly 2 minutes. After collection, samples were stored at -18^{o}C. All dust samples were passed through a pre-cleaned and hexane rinsed 500 µm mesh sieve, homogenized thoroughly, weighed and immediately transferred to clean, hexane rinsed glass vials prior to analysis.

On completion of sampling, sampling questionnaires were completed by the householders, car owners or the researcher. The questionnaires recorded details about the homes, cars and sampling rooms (i.e. room ventilation system, room flooring, number and type of electrical and electronic equipment in the monitored rooms, car manufacturer and model as well as any other observations considered relevant). Sampling locations for all domestic dust and vehicle dust samples are shown in Figure 1S (Supporting Information).

Extraction and purification of house and car dust samples

House and car dust samples were extracted and purified according to previously published methods. [25] Accurately weighed 0.15-0.25 g aliquots of each dust sample were extracted with HPLC (High Performance Liquid Chromatography) grade hexane by pressurised liquid extraction (Dionex ASE300) system, using a 66 mL cell filled from the bottom with 1.5 g of pre-extracted Florisil, pre-extracted Hydromatrix (a solid support for extractions and purifications; Varian Inc.), dust sample spiked with 10 ng of each PBDE internal standard ($^{13}C_{12}$-BDEs-28, 47, 99 and 153) and pre-extracted Hydromatrix. Extraction conditions were: temperature 100 ^{0}C, pressure 1500 psi, heat time 5 minutes, static time 4 minutes, flush volume 60%, purge time 60 seconds, static cycles 3. Following extraction, the crude extracts were purified by being reduced in volume to 0.5 mL on a Turbovap^{TM} apparatus and treated with 2 mL of concentrated sulfuric acid prior to elution through a column containing 1 g of pre-extracted Florisil, topped with 1 g of pre-extracted anhydrous sodium sulfate with 20 mL of HPLC grade hexane. The eluate was reduced under a gentle stream of nitrogen to incipient dryness before addition of 20 µL of n-nonane containing 10 ng of PCB (polychlorinated biphenyl~~s~~) 129 as recovery determination standard (RDS). The samples were reduced under nitrogen to 25 µL with 1 µL injected onto the GC/MS (gas chromatography mass spectrometry).

GC/MS analysis of PBDEs

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GC-MS measurement of tri- to hexa-BDEs (BDEs 17, 28, 47, 49, 66, 85, 99, 100, 153 and 154; Σ_{10}PBDEs) in domestic (n=53) and automobile dust samples (n=30) was conducted at the Division of Environmental Health and Risk Management, University of Birmingham, ~~the~~ United Kingdom in accordance with previously published analytical methods. [25] All PBDE analyses were performed on a Fisons GC8000 gas chromatograph coupled to a Fisons MD800 mass spectrometer equipped with an AS800 autosampler. The MS was run in electron impact ionization (EI^+) mode and helium used as carrier gas.

The Fisons MD-800 GC/MS system was fitted with a 60 m VF5 MS column (Varian, Inc; 0.25mm id, 0.25 µm film thickness). A 1µL aliquot of prepared sample extract was injected onto the column in splitless mode at an injector and interface temperature of 280 ^{0}C. Helium head pressure of 180 kpa was applied, yielding a linear flow rate of 22 to 27 cm s^{-1} during an oven temperature program of 140 ^{0}C for 2 minutes; 5 ^{0}C minute^{-1} ramp to 200 ^{0}C; 2 ^{0}C minute^{-1} to 300 ^{0}C and held for 10 minutes. The MS was operated in 5 acquisition groups in EI selected ion monitoring (SIM) mode (ionization voltage, 70 eV; ion source temperature = 250 ^{0}C) to monitor the two most abundant ions from each PBDE homologue group and QA/QC standards, 20 ions in total (for BDE-17, -28 and $^{13}C_{12}$-BDE-28: 405.8, 407.8, 417.8 and 419.8; BDE-47, -49, -66 and $^{13}C_{12}$-BDE-47: 485.8, 487.8, 495.8, 497.8; BDE-85, -99, -100 and $^{13}C_{12}$-BDE-99: 403.8, 405.8, 415.8, 417.8; and BDE-153, -154 and $^{13}C_{12}$-BDE-153: 481.7, 483.7, 493.7, 495.7; plus for QA/QC PCB standard 129 (recovery determination standard; RDS): 256.0, 258.0, 359.9 and 361.9).

Quality assurance and quality control

To assess contamination incurred during PBDE analysis, a procedural blank comprising 1 g of pre-extracted sodium sulfate (treated in the same way as the samples) was included with each batch of five samples. These procedural blanks contained <5% of the target compounds in dust samples and the data reported here are hence not blank-corrected. Average ± standard deviation percent recoveries of surrogate standards in all samples were: 77±12, 82±14, 85±15 and 81±14% for $^{13}C_{12}$-BDEs-28, 47, 99 and 153, respectively. Furthermore, method accuracy was evaluated by replicate (n=10) analysis of NIST SRM 2585 (indoor dust reference material). The results of these analyses are available as supporting information (Table 1S) and indicate both excellent reproducibility (relative standard deviations (RSDs) for BDEs 17, 28, 47, 49, 66, 85, 99, 100, 153 and 154 were 16, 5.8, 5.3, 10.4, 8.3, 7.9, 6, 12.6, 11.4 and 8.5%, respectively), and agreement with the certified values. For the purposes of calculating descriptive statistics, levels below the detection limits (DLs) were assumed to equal half the DLs. The DLs were calculated as three times the standard deviation (SD) of the blank values. The DLs for PBDEs 17, 28, 47, 49, 66, 85, 99, 100, 153 and 154 were typically 0.03 ng g^{-1}.

Statistical analysis

Throughout the study, statistical tests were performed using SPSS version 17.0 for Windows at a significance level of α = 0.05. Probability values of less than 0.05 (p<0.05) were regarded as statistically significant. Kolmogorov-Smirnov (KS) test, t-test and Principal Component Analysis (PCA) were employed for statistical analysis of a data set.

The PCA was used to systematically compare PBDE congener profiles between Thai house and car dust and also between Thai and UK house dust. This multi-variate technique reduces complex datasets from a great number of variables (in this context individual PBDE congeners) to a lesser number of Principal Components (PCs)/factors (ordinarily 3-4 PCs/factors), and ~~in~~ consequently~~ce, it~~ facilitates pattern identification within the dataset and underlines similarities and dissimilarities between different categories of samples.

Results and discussion

Concentrations of tri- to hexa-BDEs (Σ_{10}PBDEs) in house dust samples from Thailand

Concentrations of Σ_{10}PBDEs in indoor dust from Thai homes were 0.59-260 ng Σ_{10}PBDE g^{-1} (Table 1). The congener profile in all residential dust samples was dominated by BDEs 99 and 47. Levels of all BDE congeners determined in domestic dust in this study were lower than the levels reported in several countries around the world including the United Kingdom [39], the United States [41-47], Canada [41,48], Germany [42,49], Denmark [50], Sweden [51,52], Portugal [53], Australia [54,55], New Zealand [41], Iraq [56], Saudi Arabia [57], Kuwait [38,58], China [59] and Singapore [60] (Table 1). Nonetheless, the concentrations of BDE-28, 47, 99, 100 and 154; BDE-28, 47, 99, 100, 153 and 154; and BDE-47, 85, 99, 100 and 154 reported here exceed those observed in homes in Japan [61], Pakistan [38] and Egypt [62], respectively. The reasons for the low PBDE levels in domestic dust in this study are most likely due to differences in use patterns and household characteristics such as non-carpeted rooms/floor and the small number of electronics (especially laptops and personal computers) in rural Thai houses that account for 89% of total dust sampling sites. The ratios of BDE 47:99 in household dust samples were variable and ranged from 0.14-2.6 (average of 0.55, median of 0.55) (Table 2S in the supporting information).

Concentrations of tri- to hexa-BDEs (Σ_{10}PBDEs) in car dust samples from Thailand

Concentrations of Σ_{10}PBDEs in car dust were 0.68-38 ng g^{-1} (Table 2) and were lower than those detected previously in the United Kingdom [39], the United States [63,64], Portugal [53], Sweden [51], Egypt [62], Kuwait [38], Saudi Arabia. [57] and Pakistan. [38] BDEs 99 and 47 were the most abundant congeners in all our car dust samples. The ratios of BDE 47:99 in car dust samples were not constant and ranged from 0.003-6.5 (average of 0.62, median of 0.55) (Table 2 and Table 3S in the supporting information). Interestingly, the 47:99 ratios in car dust samples reported here were in line with previous results from the UK (median = 0.54) [39], the US (geometric mean = 0.62, average = 0.65) [63,64], Portugal (average = 0.60) [53], Sweden (median = 0.67) [51], Egypt (mean = 0.78) [62], Kuwait (median = 0.68) [38], Saudi Arabia (mean = 0.53) [57] and Pakistan (mean = 0.72). [38]. A t-test suggested significant differences in BDEs 47 and 99 levels between Thai (n=30) and USA vehicle dust samples (n=66) [64] (p = 0.000).

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Only a very few studies are available addressing factors affecting PBDE concentrations in cars. The study of Hazrati and Harrad (2006) [31] showed a significant positive linear relationship (p < 0.01) between PBDE concentrations in vehicle air and vehicle age, when two of the most contaminated cars were omitted as outliers. Furthermore, U.S. and Portuguese studies reported no correlations between PBDE concentrations in dust and automobile variables including year of production, car age (calculated from the date of manufacture), the extent of car use (as inferred by the mileometer reading) as well as marque and number of times cleaned. [53,63] This study did not examine the relationships between PBDE concentrations in vehicle dust and car age owing to the lack of data on automobile age.

Table 4S in the supporting information illustrate how levels of tri- to hexa-BDEs (Σ_{10}PBDEs) in dust samples from thirty vehicles vary with the different car manufacturers. The greatest average concentration of Σ_{10}PBDEs (11 ng g^{-1}) was observed in automobile dust sampled from Nissan vehicles (n=2), whilst the lowest average concentration (1.8 ng g^{-1}) was seen in car dust collected from Mitsubishi cars (n=2).

Kolmogorov-Smirnov (KS) statistical analysis revealed that the concentrations of Σ_{10}PBDEs and all PBDE congeners in house and car dust samples taken in this study deviate significantly from a normal distribution. Hence, a t-test was conducted on log-transformed values to elucidate any differences in average concentrations of PBDEs between residential and vehicle dust. The results showed that Σ_{10}PBDE concentrations in house dust were significantly higher than those in car dust (p = 0.001). In addition, levels of all congeners studied, except for BDE-28, were significantly greater in domestic dust than in automobile dust (p = <0.001-0.004), implying more extensive use of the Penta-formulation and greater tri- to hexa-BDE contamination in dwellings. The findings presented here demonstrate that Thailand could have its own fleets with Thai fire safety levels since it is a notable automobile manufacturer, and suggest further research is required to characterize PBDE contamination and its potential sources in Thai homes and cars.

PBDE congener patterns in indoor dust

In order to investigate congener patterns of PBDEs in indoor dust in more detail, PBDE congener profiles were systematically compared between Thai house and car dust and also between Thai and UK house dust using Principal Component Analysis (PCA). To examine the data via PCA, the relative fractional contribution of PBDE congeners (BDEs 17, 28, 47, 49, 66, 85, 99, 100, 153 and 154) to ΣPBDEs was calculated for each monitored sample and entered as a variable into the statistical analysis.

PBDE congener patterns in Thai house and car dust

PCA of the whole dataset comprising Thai house (n=53) and car dust samples (n=30) resulted in 10 Principal Components (PCs)/factors with eigenvalues of four PCs exceeding 1. These first four extracted PCs accounted for 75% of the variance within the data. Factor scores of PC1, PC2, PC3 and PC4 were calculated for all investigated samples included in the PCA. PC1 was mainly driven in a positive direction by high proportions of individual hexa-BDE congeners (BDEs 153 and 154), and in a negative direction by elevated proportions of BDE 99. Conversely, PC2 was principally driven in a positive direction by high proportions of BDEs 85 and 100 (penta-BDE congeners), and in a negative direction by elevated proportions of BDE 47. PCs 3 and 4 were primarily driven in a positive direction by high proportions of tetra-BDE congeners (BDEs 49 and 66) and individual tri-BDE congeners (BDEs 17 and 28) respectively. Figure 1 plots the factor scores of PC1 versus PC2 versus PC4 for Thai house and car dust. These three PCs (PC1, PC2 and PC4) accounted for 58% of the variance within the data. Plots involving PC3 proved uninformative and so are not included.

As is clear from Figure 1, there were not any differences in PBDE congener patterns between Thai house and car dust. The vast majority of house and car dust samples lie in the same area and seem to hover in the center of component space. This indicated that the tri- to hexa-BDEs detected in Thai house and car dust derive from similar sources. Nevertheless, the congener pattern in car dust appears more variable than in house dust, perhaps because cars vary more in terms of factors such as vehicle age, model, manufacturer, and country of manufacture, all of which may influence the type of flame retardant present in the vehicle. In contrast, in houses, emissions will essentially arise only from electronic and electrical goods, furniture and fabrics. Of particular interest is car dust 19 which displays a particularly distinctive profile in the guise of an elevated BDE-47:99 ratio. This may imply a distinct source or sources of PBDEs in this vehicle. However, the concentrations in this dust sample are very low, with BDEs 47 and 99 the only two congeners above detection limits, so the significance of this distinctive profile may be overestimated.

PBDE congener patterns in Thai and UK house dust

A similar comparison was carried out for PBDE congener profiles in Thai and UK house dust. The UK house dust data from the study of Muenhor and Harrad (2012) [65] were used for the examination of PBDE congener patterns because both UK house dust and Thai house dust were collected over a~~in~~ similar period. Levels of BDEs 17, 28, 47, 49, 66, 85, 99, 100, 153 and 154 were normalized to levels of ΣPBDEs and subjected to PCA. Examination of the entire dataset constituting Thai (n=53) and UK house dust samples (n=112) yielded 10 PCs with eigenvalues of four PCs exceeding 1. The first four PCs - accounting for 78% of the total variance within the dataset - were extracted. PC1 was driven in a positive direction by elevated proportions of individual hexa-BDE congeners (BDEs 153 and 154), and in a negative direction by high proportions of BDE 99. PC2 and PC3 was principally driven in a positive direction by elevated proportions of tetra-BDE congeners (BDEs 49 and 66) and individual tri-BDE congeners (BDEs 17 and 28) respectively. Moreover, PC4 was mainly driven in a positive direction by high proportions of BDEs 85 and 100 (penta-BDE congeners), and in a negative direction by elevated proportions of BDE 47. The scores for PC1 and PC2 were plotted against each other for Thai and UK house dust samples (Figure 2). These two PCs (PC1 and PC2) accounted for 49% of the variance within the data.

As Figure 2 shows, the domestic dust samples in this study occupy a region of component space represented by a line stretching from the bottom far left corner controlled by BDE 99 (where almost all of the UK house dust samples sit), to the bottom far right governed by BDEs 153 and 154 (hexa-BDE congeners). Most of our Thai dust samples sit along this line, the exceptions being eight samples, which sit in the top left quadrant of component space and appear influenced by BDEs 49 and 66 (tetra-BDE congeners). Figure 2 supports the idea that, whilst BDE 99 is the chief influence on UK house dust samples, Thai house dust samples are impacted by BDEs 49, 66, 99, 153 and 154. This supports the idea that the sources of PBDEs in Thailand differ from those in European countries such as the UK.

Environmental exposure to PBDEs via dust ingestion

Although diet is a critical pathway of exposure to PBDEs for the general population [16,49], there is mounting evidence that ingestion of indoor dust and inhalation of indoor air is also important. [36,42,48] Thus, in order to evaluate environmental exposure to the Σtri-hexa-BDEs that represent the principal congeners present in the Penta-BDE formulation, average adult and child dust ingestion figures of 20 and 50 mg day^{-1}, and high dust ingestion figures for adults and children of 50 and 200 mg day^{-1} are utilized. [36] Overall dust ingestion exposure estimates are calculated taking into account ingestion of both house and car dust. Dust ingestion is assumed to occur pro-rata to typical activity patterns (e.g. for adults and children 4.2% car and 95.8% home). [39] Assuming that the concentrations of PBDEs in microenvironments other than homes and cars are identical to those in homes, a number of dust ingestion exposure scenarios have been calculated using 5th percentile, average, median and 95th percentile concentrations in the dust samples determined in this study. In addition, the daily intake of dust has been estimated for three scenarios: namely low-end, typical and high-end exposures and the parameters used in each scenario are provided in Table 5S in the supporting information. The method for the exposure estimation is stated as follows:

Dust ingestion exposure estimates =

$$[DIR \times (4.2/100) \times (C_{car\ dust}/1{,}000)] + [DIR \times (95.8/100) \times (C_{house\ dust}/1{,}000)]$$

Where DIR is dust ingestion rate, $C_{car\ dust}$ is car dust concentration and $C_{house\ dust}$ is house dust concentration. Table 6S in the supporting information presents the environmental exposure assessments of both adults and children to BDEs 47, 99, 100, 153, 154 and Σtri-hexa-BDEs via indoor dust ingestion. At median concentrations, for example, the average-high intake of ΣPBDEs from dust ingestion is 0.19-0.49 and 0.49-1.94 ng day^{-1} for adults and children respectively. Low, typical and high PBDE exposure levels for adults are 0.026, 0.19 and 2.13 ng day^{-1}, while those for children are 0.064, 0.49 and 8.51 ng day^{-1} respectively. In this study, the average-high dust ingestion estimates at median levels for both adults and children (0.19-0.49 and 0.49-1.94 ng day^{-1}) were lower than the estimates for the UK (0.36-8.71 and 4.8-17.4 ng day^{-1}) [66], Canada (7.5-180 and 99-360 ng day^{-1}) [48] and Singapore (4.8-116 and 64-232 ng day^{-1}). [60] This is a result of the lower PBDE concentration~~tent~~s in domestic dust in Thailand, particularly when compared with the ~~contamination~~ concentrations in the United States [41-47] and Canada. [41,48] When compared with a chronic oral RfD for BDE-99 proposed by the US EPA (100 ng/kg bw/day), all exposure estimates for Thai adults and children were well within the RfD (Table 3).

Conclusions

The present study is the first to examine contamination by tri- to hexa-BDEs (BDEs 17, 28, 47, 49, 66, 85, 99, 100, 153 and 154) in Thai cars. PBDEs were observed in all domestic dust samples, and the congener pattern for the residential dust was predominated by BDE 99 and 47. Principal Component Analysis (PCA) suggested no differences in PBDE congener profiles between Thai house and car dust. For Thai and UK residential dust, the PCA indicated that, while BDEs 49, 66, 99, 153 and 154 are the crucial influences on Thai samples, the UK samples are primarily governed by BDE 99. PBDE concentrations in indoor dust and dust ingestion exposure estimates are comparable to those reported in other countries. Estimated environmental exposures of Thai adults and children to BDE-99 via dust ingestion were well within a chronic oral RfD for BDE-99 proposed by the US EPA. The findings of this preliminary study revealed that PBDEs are ubiquitous contaminants in Thai indoor environments such as houses and vehicles, and that the Thai population is continuously exposed to low levels of these compounds via indoor dust ingestion. Further investigations are needed into the mechanism of environmental exposure to indoor PBDEs via dust ingestion and the factors playing a prominent role in exposure and in PBDE contamination of indoor environments.

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FIGURE CAPTIONS

Figure 1. Plot of scores for principal component 1 versus principal component 2 versus principal component 4 for Thai house and car dust.

Figure 2. Plot of scores for principal component 1 versus principal component 2 for Thai and UK house dust.

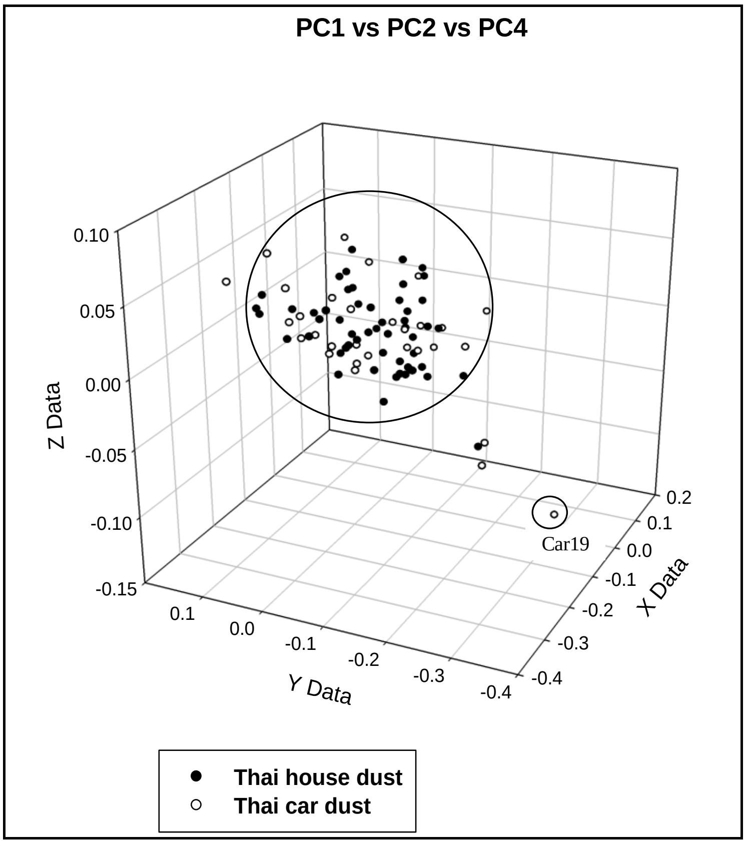
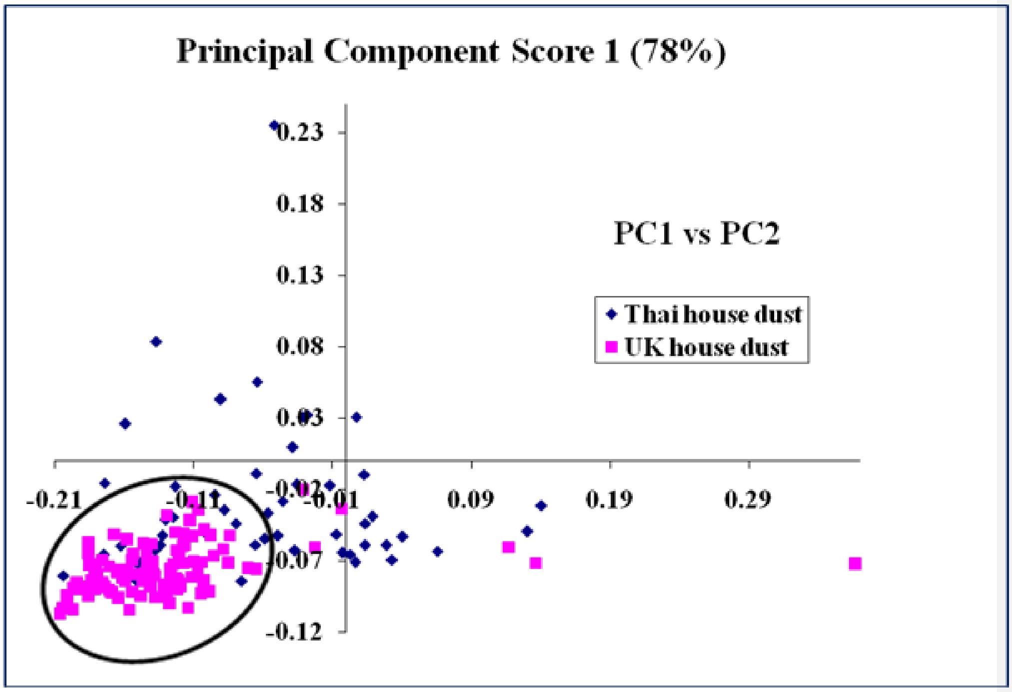

PC1 vs PC2 vs PC4
Z Data
0.10
0.05
0.00
-0.05
-0.10
-0.15
Y Data
0.1
0.0
-0.1
-0.2
-0.3
-0.4
X Data
0.2
0.1
0.0
-0.1
-0.2
-0.3
-0.4
Car19
Thai house dust
Thai car dust

Fig. 1



Principal Component Score 1 (78%)
PC1 vs PC2
Thai house dust
UK house dust
0.23
0.18
0.13
0.08
0.03
-0.02
-0.07
-0.12
-0.21
-0.11
-0.01
0.09
0.19
0.29

Fig. 2

Table 1. Summary of PBDE concentrations (ng g^{-1}) in house dust samples from Thailand and selected other studies.

Location (reference)	Statistical parameter/ congener	17	28	47	49	66	85	99	100	153	154	Σ_{10} PBDEs[a]
Various provinces, Thailand, this study, Thirty homes, n=53[b]	Average[c]	0.05	0.14	3.7	0.73	0.40	0.85	6.7	1.4	1.9	1.4	17
	σ_n[c]	0.06	0.14	8.3	1.2	0.76	1.2	19	2.9	3.3	2.9	36
	Median[c]	0.015	0.10	1.9	0.20	0.13	0.38	3.4	0.72	0.91	0.48	10
	Minimum	<0.03	<0.03	0.12	<0.03	<0.03	<0.03	0.19	<0.03	<0.03	<0.03	0.59
	Maximum	0.32	0.55	59	6.0	5.0	5.3	138	21	17	18	257
	Percentile 5[c]	0.015	0.015	0.22	0.015	0.015	0.015	0.40	0.05	0.015	0.015	1.3
	Percentile 95[c]	0.18	0.43	9.1	3.3	1.3	3.1	13	3.8	7.3	4.7	43
Birmingham, UK, n=30[39]	Average	-	0.70	15	-	-	-	36	5.6	14	4.4	-
Different cities, Sweden, n=5[52]	Average	-	2.2	51	-	3.3	-	79	24	4.9	3.9	-
Stockholm, Sweden, n=10[51]	Median	-	1.3	42	-	-	-	52	-	6.6	-	-
	Minimum	-	<0.1	<0.5	-	-	-	<1	-	0.61	-	-
	Maximum	-	5.6	230	-	-	-	140	-	23	-	-
Various locations, Germany, n=10[42]	Median	-	-	<14	-	-	-	10	<6	<6	-	-
	Minimum	-	-	<14	-	-	-	<4	<6	<6	<6	-
	Maximum	-	-	22	-	-	-	28	7	22	-	-
Munich, Germany, n=34[49]	Median	-	0.25	9.08	-	0.19	-	12.5	2.49	2.69	1.62	-
Copenhagen, Denmark, n=42[50]	Average	0.45	-	62.5	1.91	1.06	3.04	78.1	12.8	9.96	6.49	-
	Median	0.19	-	16.9	0.44	0.31	0.54	13.6	2.46	2.48	1.29	-
	Minimum	<LOQ	-	3.29	<LOQ	<LOQ	<LOQ	2.72	0.35	0.55	0.12	-
	Maximum	3.4	-	962	25.6	19.8	67	1,764	292	182	143	-
Porto region, Portugal, Sieved fraction, n=11[53]	Average	-	0.40	25	21	2.9	n.d.	9.8	1.9	2.5	0.60	-
Washington DC, USA, n=17[43]	Mean	8.9	-	1,220	-	29	83	1,700	274	181	156	-
	Median	4.2	-	644	-	13	33	676	119	64	73	-
Amarillo & Austin, TX, USA, n=20[41]	Average	-	25	810	-	-	-	1,400	240	240	240	-
Durham, North Carolina, USA, n=81[47]	Geometric mean	2.7	11	870	-	14	-	919	176	88	74	-
	Minimum	<1.2	<1.5	55	-	<1.1	-	8	9	7	5	-
	Maximum	94	277	24,720	-	916	-	36,210	10,230	3,407	3,061	-

Table 1 continued. Summary of PBDE concentrations (ng g^{-1}) in house dust samples from Thailand and selected other studies.

Location (reference)	Statistical parameter/ congener	17	28	47	49	66	85	99	100	153	154	Σ_{10} PBDEs[a]
Boston, MA, USA, Main living area, n=20[44]	Geometric mean	1.4	-	1,865	30	17	-	2,460	436	234	183	-
	Minimum	<0.1	-	445	0.3	0.2	-	331	71	28	27	-
	Maximum	112	-	16,840	372	287	-	24,510	4,274	2,377	2,061	-
Atlanta, GA, USA, n=10[42]	Median	-	-	430	-	-	-	880	150	140	80	-
California, USA, n=49[45]	Median	-	-	2,700	-	-	-	3,800	684	-	-	-
Massachusetts, USA, n=24[46]	Geometric mean	-	-	577	-	-	-	809	220	-	-	-
Ottawa, Canada, n=74[48]	Mean	4.3	15	1,100	-	37	190	1,800	490	470	380	-
	Median	1.0	3.0	300	-	4.7	17	430	73	49	37	-
Toronto, Canada, n=10[41]	Average	-	6.6	300	-	-	-	510	120	71	69	-
Cairo, Egypt, n= 17[62]	Mean	2.62	0.70	29	-	1.37	3.64	34.9	7.18	27.8	4.94	-
	Median	1.7	0.34	1.7	-	0.64	0.23	2.7	0.37	6.26	0.38	-
	Minimum	0.21	0.15	0.34	-	0.23	0.04	0.53	0.07	0.54	<MDL	-
	Maximum	14.3	4.12	375	-	7.49	28.9	509.8	97.7	194.7	60.1	-
Kuwait, n=17[58]	Average	-	0.35	6.6	-	-	0.72	6.0	1.2	1.3	1.4	-
	Median	-	0.12	2.7	-	-	0.40	3.4	0.68	0.72	0.85	-
Kuwait city, Kuwait, n=15[38]	Median	-	0.4	9.5	-	-	-	12	2.3	2.4	1.3	
Jeddah, Saudi Arabia, n=15[57]	Mean	-	1.0	130	-	-	-	220	35	25	20	-
	Median	-	1.0	27	-	-	-	35	5.0	4.0	3.0	-
	Minimum	-	LOQ	3.0	-	-	-	5.0	LOQ	LOQ	LOQ	-
	Maximum	-	1.0	1,500	-	-	-	2,700	450	310	210	-
Basrah, Iraq, n=48[56]	Mean	-	0.31	7.66	-	-	-	11	1.64	4.32	1.94	-
	Median	-	<0.1	3.6	-	-	-	6.67	0.6	0.54	0.61	-
	Minimum	-	<0.1	<0.1	-	-	-	<0.1	<0.2	<0.01	<0.1	-
	Maximum	-	1.2	37.6	-	-	-	49.2	7.43	16.9	11.3	-
Faisalabad, Pakistan, n=15[38]	Median	-	<0.1	1.3	-	-	-	1.7	0.3	0.6	0.4	

Table 1 continued. Summary of PBDE concentrations (ng g^{-1}) in house dust samples from Thailand and selected other studies.

Location (reference)	Statistical parameter/ congener	17	28	47	49	66	85	99	100	153	154	Σ_{10} PBDEs[a]
Brisbane, Queensland, Australia, n=10[54]	Average	-	-	91	-	-	-	184	38	23	-	-
South East Queensland, Australia, n=5[55]	Average	-	-	2.4	-	-	-	36	7.0	6.8	4.0	-
Wellington, New Zealand, n=20[41]	Average	-	0.86	36	-	-	-	87	16	9.8	8.7	-
Hokkaido, Japan, n=2[61]	Average	-	<0.03	2.5	-	-	-	2.8	0.54	2.0	0.99	-
Hangzhou, China, n=10[59]	Average	-	0.38	7.3	-	-	-	5.3	0.73	0.73	4.4	-
	Geometric mean	-	0.36	5.2	-	-	-	4.0	0.48	0.63	0.58	-
	Median	-	0.36	4.0	-	-	-	3.6	0.55	0.76	0.48	-
	Minimum	-	0.16	1.4	-	-	-	0.63	0.12	0.28	0.15	-
	Maximum	-	0.61	18	-	-	-	15	3.1	1.5	39	-
Various locations, Singapore, n=31[60]	Mean	-	1.2	110	-	-	-	340	65	76	43	-
	Median	-	0.6	20	-	-	-	24	4.2	6.9	3.5	-

[a] Sum of PBDEs 17, 28, 47, 49, 66, 85, 99, 100, 153 and 154.

[b] The samples were collected in December 2007-January 2008, and this is not the same as the year the paper was published.

[c] For purposes of calculating descriptive statistics, values <dl assumed to equal 0.5 x dl (for PBDEs 17, 28, 47, 49, 66, 85, 99, 100, 153 and 154 dl = 0.03 ng g^{-1}).

Table 2. Summary of PBDE concentrations (ng g^{-1}) in car dust samples from Thailand and selected other studies.

Congener/ location	17	28	47	49	66	85	99	100	153	154	Σ_{10}PBDEs[a]	BDE47:99 ratio
Thailand, this study, Cars, n=30[b]												
Average[c]	0.04	0.32	1.8	0.24	0.25	0.25	3.0	0.45	0.45	0.23	7.0	0.62
σ_n[c]	0.08	1.3	3.4	1.0	1.2	0.44	4.8	0.82	0.80	0.29	10	-
Median[c]	0.015	0.015	0.64	0.015	0.015	0.11	1.2	0.14	0.22	0.015	3.0	0.55
Minimum	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	0.18	<0.03	<0.03	<0.03	0.68	0.003
Maximum	0.36	6.8	16	5.7	6.4	2.0	22	3.3	4.3	0.84	38	6.5
Percentile 5[c]	0.015	0.015	0.05	0.015	0.015	0.015	0.24	0.015	0.015	0.015	1.0	-
Percentile 95[c]	0.17	1.1	8.7	0.53	0.18	1.2	12	2.5	1.2	0.79	32	-
Birmingham, UK, n=20[39]												
Average	-	6.1	720	-	-	-	990	220	150	160	-	0.73
σ_n	-	13	2,000	-	-	-	2,400	560	360	440	-	-
Median	-	<0.5	54	-	-	-	100	17	11	11	-	0.54
Minimum	-	<0.5	19	-	-	-	23	<0.5	<0.5	<0.5	-	-
Maximum	-	43	7,500	-	-	-	8,000	2,300	1,500	1,900	-	-
New Jersey & Pennsylvania, USA, n=60[63]												
Mean	-	154	1,233	-	-	-	1,989	345	552	194	-	0.62
Median	-	118	880	-	-	-	1,130	211	163	105	-	0.78
Minimum	-	<3.2	139	-	-	-	201	32	43	21	-	-
Maximum	-	763	13,600	-	-	-	22,900	3,870	16,600	2,050	-	-
Pennsylvania, USA, n=66[64]												
Average	7.4	17.3	1,950	119	29.9	-	2,990	372	266	153	-	0.65
Median	2.1	4.8	590	22.5	7.6	-	613	78.5	71.5	10.4	-	0.96
Porto region, Portugal, n=9[53]												
Average	-	8.8	387	26	8.4	56	650	161	148	110	-	0.60
σ_n	-	14	621	16	12	119	1,028	301	301	225	-	-
Median	-	4.0	88	26	3.0	6.0	126	23	23	12	-	0.70
Minimum	-	<dl	26	9.0	<dl	<dl	13	2	1	2	-	-
Maximum	-	46	1,549	57	37	368	3,104	914	937	697	-	-

Table 2 continued. Summary of PBDE concentrations (ng g^{-1}) in car dust samples from Thailand and selected other studies.

Congener/ location	17	28	47	49	66	85	99	100	153	154	BDE47:99 ratio
Stockholm, Sweden, n=10[51]											
Median	-	0.20	7.4	-	-	-	11	-	3.1	-	0.67
Minimum	-	<0.1	0.56	-	-	-	1.5	-	0.25	-	-
Maximum	-	0.4	22	-	-	-	30	-	6.7	-	-
Cairo, Egypt, n= 9[62]											
Mean	5.33	2.50	25.9	-	2.23	1.68	33.0	6.67	25.4	5.94	0.78
Median	2.56	1.18	5.69	-	1.77	0.93	22.5	4.82	16.3	3.64	0.25
Minimum	0.94	0.67	0.49	-	0.58	0.13	1.51	0.09	4.03	0.57	-
Maximum	25.5	12.0	111	-	5.80	5.79	123	25.1	74.9	21.0	-
Kuwait city, Kuwait, n=15[38]											
Mean	-	0.3	6.8	-	-	-	14.7	3.4	6.7	1.6	0.46
Median	-	0.2	5.8	-	-	-	8.5	1.5	1.5	1.1	0.68
Minimum	-	<0.2	0.6	-	-	-	1.0	<0.2	<0.2	<0.2	-
Maximum	-	2	14.5	-	-	-	62	17	70	6	-
Jeddah, Saudi Arabia, n=15[57]											
Mean	-	LOQ	21	-	-	-	40	7	6	3	0.53
Median	-	LOQ	10	-	-	-	9	2	1.5	1.5	1.11
Minimum	-	-	LOQ	-	-	-	LOQ	LOQ	LOQ	LOQ	-
Maximum	-	-	200	-	-	-	400	700	30	25	-
Faisalabad, Pakistan, n=15[38]											
Mean	-	0.2	1.8	-	-	-	2.5	0.4	1.0	0.4	0.72
Median	-	<0.1	1.2	-	-	-	1.7	0.3	0.9	0.3	0.71
Minimum	-	<0.1	<0.2	-	-	-	0.4	<0.2	<0.2	<0.2	-
Maximum	-	1.3	7.5	-	-	-	8.0	1.5	2.2	0.8	-

[a] Sum of PBDEs 17, 28, 47, 49, 66, 85, 99, 100, 153 and 154.
[b] The samples were collected in December 2007-January 2008, and this is not the same as the year the paper was published.
[c] For purposes of calculating descriptive statistics, values <dl assumed to equal 0.5 x dl (for PBDEs 17, 28, 47, 49, 66, 85, 99, 100, 153 and 154 dl = 0.03 ng g^{-1}).

Table 3. Comparison of adult and child exposure to BDE-99 via dust ingestion (ng/kg bw/day) with exposure guideline.

Exposure pathway	**BDE-99**		
	Adult[a]	**Male children**[b,d]	**Female children**[c,d]
Dust ingestion			
Low-end exposure	0.0001	0.0017	0.0019
Typical exposure	0.0012	0.0146	0.0165
High-end exposure	0.0116	0.2229	0.2510
US EPA's RfD	100[e]	100[e]	100[e]

[a] Assumed adult weight of 56 kg.[67]
[b] Assumed male child weight of 11.62 kg.[68]
[c] Assumed female child weight of 10.32 kg.[68]
[d] Two-year-old children were selected for exposure assessment as they are considered particularly prone to dust ingestion.
[e] [69]

SUPPORTING INFORMATION

Figure 1S. Map of house and car dust sampling locations in Thailand.

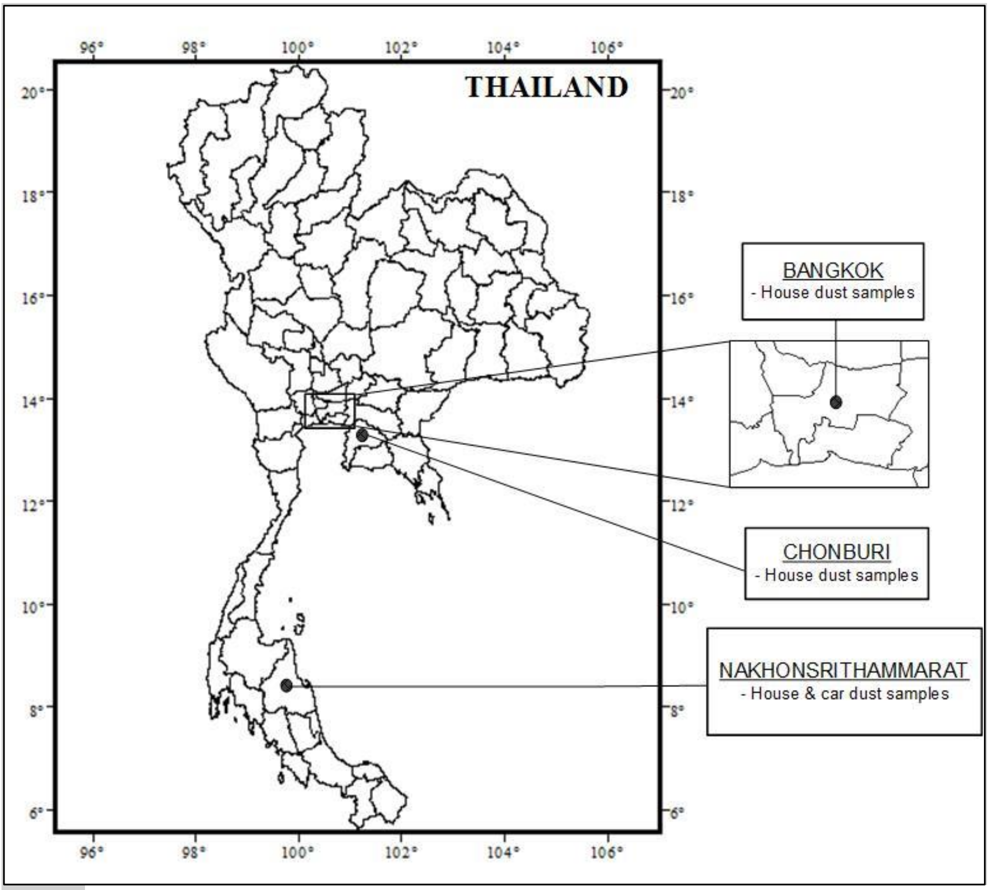


Fig. 1S

Table 1S. Concentrations (ng g^{-1} dw) of PBDE congeners in indoor dust reference materials SRM 2585 (n=10).

PFRs	Certified value	Experimental value	
	Average ± SD	Average ±SD	%RSD
BDE 17	11.5±1.2	14.9±2.38	15.96
BDE 28	46.9±4.4	45.8±2.66	5.8
BDE 47	497±46	442.9±23.3	5.26
BDE 49	53.5±4.2	54.7±5.68	10.38
BDE 66	na	33.4±2.76	8.25
BDE 85	43.8±1.6	41±3.23	7.88
BDE 99	892±53	827±49.39	5.97
BDE 100	145±11	141.5±17.8	12.58
BDE 153	119±1	116.7±13.33	11.42
BDE 154	83.5±2	87.7±7.48	8.53

na = no data available

Table 2S. Concentrations of PBDEs (ng g^{-1}) in house dust samples from Thailand.

Congener/ Sample	17	28	47	49	66	85	99	100	153	154	Σ_{10}PBDEs[a]	BDE47:99 ratio
TH-HD 1	0.32	0.55	13	0.51	0.19	1.8	14	3.7	17	5.9	58	0.94
TH-HD 2	0.09	0.31	2.2	0.11	0.04	2.4	6.1	2.5	4.0	1.9	20	0.35
TH-HD 3	0.07	0.11	3.6	0.13	0.34	4.6	13	4.1	10	3.9	40	0.28
TH-HD 4	0.06	0.12	2.2	0.37	0.22	0.41	2.9	0.72	4.6	2.7	14	0.77
TH-HD 5	0.19	0.21	6.3	3.2	2.1	3.7	6.7	2.9	5.0	3.4	34	0.95
TH-HD 6	<0.03	0.23	2.7	0.40	0.82	2.7	6.9	2.4	4.1	2.9	23	0.39
TH-HD 7	<0.03	0.31	3.0	0.52	0.39	2.4	5.6	1.9	1.6	0.32	16	0.54
TH-HD 8	0.04	0.55	59	1.8	<0.03	5.3	138	21	14	18	257	0.43
TH-HD 9	<0.03	<0.03	9.8	4.6	0.97	1.8	15	1.2	5.3	9.8	49	0.65
TH-HD 10	<0.03	0.26	1.5	0.09	0.08	0.20	4.4	0.23	0.74	1.1	8.6	0.35
TH-HD 11	<0.03	0.08	0.92	0.06	0.03	0.21	1.8	0.38	0.12	0.08	3.7	0.51
TH-HD 12	<0.03	<0.03	0.52	0.06	<0.03	0.06	0.47	0.08	0.15	0.12	1.5	1.1
TH-HD 13	<0.03	<0.03	0.30	0.09	0.13	0.05	0.58	0.06	0.74	0.66	2.6	0.52
TH-HD 14	0.11	0.09	1.3	0.05	0.07	1.1	2.5	1.1	1.2	1.2	8.7	0.51
TH-HD 15	0.18	0.10	1.9	0.46	0.89	0.59	1.7	0.80	0.90	0.58	8.1	1.1
TH-HD 16	<0.03	<0.03	0.29	0.08	0.06	<0.03	1.1	0.28	0.11	0.08	2.0	0.27
TH-HD 17	<0.03	0.06	1.3	0.51	<0.03	1.5	9.1	4.6	0.80	0.20	18	0.14
TH-HD 18	<0.03	0.18	1.5	6.0	5.0	1.5	3.9	1.1	1.1	0.92	21	0.39
TH-HD 19	0.05	0.05	0.63	0.48	0.35	0.70	3.2	0.91	0.43	0.15	6.9	0.20
TH-HD 20	0.04	0.05	7.2	2.3	0.24	0.22	2.8	0.19	1.3	0.48	15	2.6
TH-HD 21	<0.03	0.04	0.94	0.08	0.71	1.3	3.7	2.9	0.28	0.17	10	0.25
TH-HD 22	0.05	0.17	5.7	2.4	1.7	0.58	7.2	0.65	1.4	0.88	21	0.79
TH-HD 23	<0.03	<0.03	1.2	0.87	0.29	0.49	2.3	1.0	0.78	0.76	7.7	0.50
TH-HD 24	<0.03	0.07	0.84	0.13	0.11	0.22	1.6	0.26	0.33	0.29	3.8	0.54
TH-HD 25	0.04	0.05	0.13	0.10	<0.03	0.09	0.52	0.28	0.34	0.32	1.9	0.25
TH-HD 26	<0.03	0.04	0.22	<0.03	<0.03	0.17	0.30	0.22	0.06	<0.03	1.1	0.73
TH-HD 27	<0.03	0.12	0.75	<0.03	0.04	0.04	0.84	0.05	<0.03	<0.03	1.9	0.89
TH-HD 28	<0.03	0.15	1.4	0.05	0.06	0.37	2.6	0.47	0.23	0.07	5.4	0.52
TH-HD 29	<0.03	<0.03	0.21	<0.03	0.04	<0.03	0.19	<0.03	0.12	<0.03	0.65	1.1
TH-HD 30	<0.03	0.04	0.12	<0.03	<0.03	<0.03	0.19	<0.03	0.11	0.05	0.59	0.63
TH-HD 31	<0.03	<0.03	1.3	0.16	0.07	0.64	2.5	1.6	0.91	0.81	8.0	0.54
TH-HD 32	<0.03	<0.03	2.2	0.09	0.13	1.0	8.1	2.0	<0.03	<0.03	14	0.27

Table 2S continued. Concentrations of PBDEs (ng g^{-1}) in house dust samples from Thailand.

Congener/ Sample	17	28	47	49	66	85	99	100	153	154	Σ_{10} PBDEs[a]	BDE47:99 ratio
TH-HD 33	0.09	0.12	1.0	0.32	0.47	2.2	6.5	2.6	0.94	<0.03	14	0.15
TH-HD 34	<0.03	0.15	4.9	0.17	0.12	0.28	3.5	1.3	1.7	0.69	13	1.4
TH-HD 35	<0.03	0.20	3.8	0.31	<0.03	0.67	5.7	0.82	3.0	2.1	17	0.67
TH-HD 36	0.03	0.16	0.84	0.64	0.06	0.06	1.0	0.30	0.31	<0.03	3.4	0.82
TH-HD 37	<0.03	0.07	0.41	0.11	0.10	<0.03	2.0	0.04	0.18	<0.03	2.9	0.21
TH-HD 38	0.06	0.12	0.75	0.09	0.08	0.10	1.4	0.10	0.68	0.64	4.0	0.53
TH-HD 39	0.04	0.07	2.1	0.34	0.10	0.06	3.1	0.09	0.52	0.13	6.5	0.70
TH-HD 40	0.09	0.19	4.8	0.84	0.07	0.09	3.0	0.21	1.9	1.1	12	1.6
TH-HD 41	0.14	0.25	2.3	0.64	0.19	0.38	3.6	0.73	2.1	1.8	12	0.63
TH-HD 42	<0.03	<0.03	1.3	0.48	0.19	0.20	2.7	0.55	<0.03	<0.03	5.5	0.47
TH-HD 43	0.07	0.54	8.6	<0.03	0.78	0.67	11	0.96	1.1	0.86	25	0.76
TH-HD 44	<0.03	0.04	2.0	<0.03	0.45	0.22	2.1	0.27	0.94	0.39	6.5	0.93
TH-HD 45	0.04	0.08	0.97	0.35	0.29	0.08	1.6	0.11	<0.03	<0.03	3.5	0.62
TH-HD 46	0.14	0.32	4.7	3.4	0.74	0.65	5.0	1.0	<0.03	<0.03	16	0.94
TH-HD 47	0.05	0.08	1.4	0.20	0.09	0.28	5.1	0.65	<0.03	<0.03	7.9	0.27
TH-HD 48	0.12	0.22	7.0	1.7	1.0	0.94	8.3	1.4	2.2	1.9	25	0.84
TH-HD 49	0.20	0.36	3.4	1.9	0.53	0.30	4.1	0.41	3.0	<0.03	14	0.82
TH-HD 50	<0.03	0.26	3.9	0.12	0.25	0.15	4.1	0.38	2.6	2.3	14	0.95
TH-HD 51	<0.03	0.04	1.9	0.06	0.32	0.25	3.4	0.34	1.0	0.68	8.0	0.55
TH-HD 52	<0.03	0.04	4.2	0.20	0.05	0.51	4.5	0.91	1.6	0.72	13	0.92
TH-HD 53	0.06	0.19	2.4	0.95	0.10	0.75	4.5	0.97	1.1	0.36	11	0.53
Average[b]	0.05	0.14	3.7	0.73	0.40	0.85	6.7	1.4	1.9	1.4	17	0.55
σ_n[b]	0.06	0.14	8.3	1.2	0.76	1.2	19	2.9	3.3	2.9	36	0.41
Median[b]	0.015	0.10	1.9	0.20	0.13	0.38	3.4	0.72	0.91	0.48	10	0.55
Minimum	<0.03	<0.03	0.12	<0.03	<0.03	<0.03	0.19	<0.03	<0.03	<0.03	0.59	0.14
Maximum	0.32	0.55	59	6.0	5.0	5.3	138	21	17	18	257	2.6
Percentile 5[b]	0.015	0.015	0.22	0.015	0.015	0.015	0.40	0.05	0.015	0.015	1.3	0.20
Percentile 95[b]	0.18	0.43	9.1	3.3	1.3	3.1	13	3.8	7.3	4.7	43	1.2

[a] Sum of PBDEs 17, 28, 47, 49, 66, 85, 99, 100, 153 and 154.
[b] For purposes of calculating descriptive statistics, values <dl assumed to equal 0.5 x dl (for PBDEs 17, 28, 47, 49, 66, 85, 99, 100, 153 and 154 dl = 0.03 ng g^{-1}).

Table 3S. Concentrations of PBDEs (ng g^{-1}) in car dust samples from Thailand.

Congener/ location	17	28	47	49	66	85	99	100	153	154	Σ_{10}PBDEs[a]	BDE47:99 ratio
Thailand, this study, Cars, n=30												
TH Car 1-Nissan	<0.03	<0.03	0.38	<0.03	<0.03	2.0	2.1	0.85	4.3	0.63	10	0.18
TH Car 2-Isuzu	<0.03	<0.03	0.49	<0.03	<0.03	0.35	1.4	0.23	<0.03	<0.03	2.6	0.34
TH Car 3-Isuzu	<0.03	<0.03	1.1	<0.03	<0.03	<0.03	0.49	<0.03	1.3	0.78	3.8	2.3
TH Car 4-Toyota	<0.03	<0.03	0.66	<0.03	<0.03	0.14	0.37	0.15	0.34	0.25	2.0	1.8
TH Car 5-Isuzu	0.30	6.8	16	5.7	6.4	<0.03	2.4	<0.03	<0.03	<0.03	38	6.5
TH Car 6-Mitzubishi	<0.03	<0.03	1.7	<0.03	<0.03	<0.03	1.1	<0.03	<0.03	<0.03	2.9	1.6
TH Car 7-Isuzu	<0.03	<0.03	0.68	<0.03	<0.03	<0.03	2.5	<0.03	<0.03	<0.03	3.3	0.28
TH Car 8-Isuzu	<0.03	0.33	11	0.37	<0.03	0.29	22	3.3	0.98	<0.03	38	0.48
TH Car 9-Isuzu	<0.03	<0.03	1.1	0.06	0.11	0.18	1.3	0.18	0.74	0.79	4.4	0.86
TH Car 10-Isuzu	<0.03	<0.03	0.62	<0.03	0.11	0.04	0.40	0.13	0.49	0.26	2.1	1.6
TH Car 11-Ford	<0.03	<0.03	1.5	<0.03	0.11	0.13	2.8	0.49	0.26	<0.03	5.3	0.52
TH Car 12-Toyota	<0.03	<0.03	3.4	<0.03	<0.03	1.3	11	2.4	0.79	0.71	19	0.32
TH Car 13-Isuzu	<0.03	<0.03	0.23	<0.03	0.05	0.10	0.87	0.13	0.68	0.18	2.3	0.26
TH Car 14-Toyota	<0.03	<0.03	0.23	<0.03	<0.03	0.09	0.18	0.16	0.32	0.47	1.5	1.3
TH Car 15-Toyota	<0.03	<0.03	0.52	<0.03	<0.03	0.07	0.73	0.11	0.28	0.25	2.0	0.71
TH Car 16-Toyota	<0.03	<0.03	1.3	<0.03	<0.03	0.20	2.1	0.52	0.92	0.84	6.0	0.62
TH Car 17-Toyota	0.36	1.6	6.1	0.06	<0.03	0.20	14	2.5	0.78	0.63	26	0.45
TH Car 18-Honda	<0.03	<0.03	0.57	<0.03	<0.03	0.10	0.65	0.32	0.19	<0.03	1.9	0.88
TH Car 19-Toyota	<0.03	<0.03	1.3	<0.03	<0.03	<0.03	0.23	<0.03	<0.03	<0.03	1.6	5.6
TH Car 20-Isuzu	<0.03	<0.03	0.53	<0.03	<0.03	<0.03	0.26	<0.03	<0.03	<0.03	0.91	2.0
TH Car 21-Isuzu	<0.03	0.59	1.9	0.66	0.24	0.12	1.6	0.10	0.25	<0.03	5.5	1.1
TH Car 22-Toyota	<0.03	<0.03	0.80	<0.03	<0.03	0.21	2.2	0.15	<0.03	<0.03	3.5	0.36
TH Car 23-Isuzu	<0.03	<0.03	0.58	<0.03	<0.03	0.27	0.86	0.24	0.13	0.17	2.3	0.67
TH Car 24-Toyota	<0.03	<0.03	0.18	<0.03	<0.03	0.04	0.59	0.12	0.15	<0.03	1.2	0.31
TH Car 25-Isuzu	<0.03	<0.03	0.48	<0.03	<0.03	0.10	0.53	0.09	0.14	0.20	1.6	0.91
TH Car 26-Toyota	<0.03	<0.03	0.09	<0.03	<0.03	<0.03	0.89	<0.03	<0.03	<0.03	1.1	0.10
TH Car 27-Isuzu	<0.03	<0.03	<0.03	<0.03	<0.03	1.0	4.9	<0.03	<0.03	<0.03	6.1	0.003
TH Car 28-Isuzu	<0.03	<0.03	0.41	<0.03	<0.03	0.21	2.1	0.17	<0.03	<0.03	3.0	0.19
TH Car 29-Mitzubishi	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	0.54	<0.03	<0.03	<0.03	0.68	0.03
TH Car 30-Nissan	<0.03	<0.03	1.4	<0.03	<0.03	0.19	8.1	0.93	0.42	0.36	11	0.17
Average[b]	0.04	0.32	1.8	0.24	0.25	0.25	3.0	0.45	0.45	0.23	7.0	0.62
σ_n[b]	0.08	1.3	3.4	1.0	1.2	0.44	4.8	0.82	0.80	0.29	10	-
Median[b]	0.015	0.015	0.64	0.015	0.015	0.11	1.2	0.14	0.22	0.015	3.0	0.55
Minimum	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	0.18	<0.03	<0.03	<0.03	0.68	0.003
Maximum	0.36	6.8	16	5.7	6.4	2.0	22	3.3	4.3	0.84	38	6.5
Percentile 5[b]	0.015	0.015	0.05	0.015	0.015	0.015	0.24	0.015	0.015	0.015	1.0	-
Percentile 95[b]	0.17	1.1	8.7	0.53	0.18	1.2	12	2.5	1.2	0.79	32	-

Table 4S. PBDE concentrations (range in parentheses) in car dust samples (ng g^{-1}) from different car manufacturers.

Car manufacturer (Country of origin: Thailand)	Car dust concentrations of Σ_{10}PBDEs (ng g^{-1})		
	Number	**Average**	**SD**
Isuzu	14	8.1 (0.91-38)	13
Toyota	10	6.4 (1.1-26)	8.8
Nissan	2	11 (10-11)	0.71
Mitzubishi	2	1.8 (0.68-2.9)	1.6
Honda	1	1.9	-
Ford	1	5.3	-

Table 5S. Parameters utilized in dust ingestion exposure scenarios.

Scenario	**Concentration**	**Dust ingestion rate**
Low-end exposure	5^{th} percentile	Average
Typical exposure	Median	Average
High-end exposure	95^{th} percentile	High

Table 6S. Estimated exposures to PBDEs (ng day^{-1}) via dust ingestion from this and other studies.

Exposure pathway	BDE-47		BDE-99		BDE-100		BDE-153		BDE-154		ΣPBDEs[a]	
	Adults (ng day^{-1})	Children (ng day^{-1})	Adults (ng day^{-1})	Children (ng day^{-1})	Adults (ng day^{-1})	Children (ng day^{-1})	Adults (ng day^{-1})	Children (ng day^{-1})	Adults (ng day^{-1})	Children (ng day^{-1})	Adults (ng day^{-1})	Children (ng day^{-1})
<u>Dust ingestion, this study</u>												
-low-end exposure	0.0043	0.011	0.0079	0.02	0.00097	0.0024	0.0003	0.00075	0.0003	0.00075	0.026	0.064
-typical exposure	0.037	0.092	0.066	0.17	0.014	0.035	0.018	0.044	0.0092	0.023	0.19	0.49
-high-end exposure	0.45	1.82	0.65	2.59	0.19	0.75	0.35	1.41	0.23	0.91	2.13	8.51
<u>Average-high dust ingestion rate, this study</u>												
-median concentration	-	-	-	-	-	-	-	-	-	-	0.19-0.49	0.49-1.94
-5th percentile concentration	-	-	-	-	-	-	-	-	-	-	0.026-0.064	0.064-0.26
-95th percentile concentration	-	-	-	-	-	-	-	-	-	-	0.85-2.13	2.13-8.51
<u>Average-high dust ingestion rate, other studies</u>												
-95th percentile concentration	-	-	-	-	-	-	-	-	-	-	2.4-58.7[b]	32.3-117.3[b]
-median concentration	-	-	-	-	-	-	-	-	-	-	0.36-8.71[b]	4.8-17.4[b]
-median concentration	-	-	-	-	-	-	-	-	-	-	4.8-116[c]	64-232[c]
-median concentration	-	-	-	-	-	-	-	-	-	-	7.5-180[d]	99-360[d]

[a] Sum of PBDEs 17, 28, 47, 49, 66, 85, 99, 100, 153 and 154.
[b] [66] (sum of PBDEs 28, 47, 49, 66, 85, 99, 100, 153 and 154).
[c] [60] (sum of PBDEs 28, 47, 99, 100, 153, 154, 183 and 209).
[d] [48] (sum of PBDEs 17, 28, 47, 66, 71, 85, 99, 100, 138, 153, 154, 183, 190 and 209).